SHORT REPORT

Lung cancer risk among US radiologic technologists, 1983–1998

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While exposure to moderate to high-dose ionizing radiation is an established risk factor for lung cancer, the relationship between lung cancer and chronic low dose radiation remains uncertain. We examined lung cancer risk among 71,894 US radiologic technologists who were certified during 1926–1982, responded to a baseline questionnaire (1983–1989), and were free of cancer other than non-melanoma skin cancer at baseline. Study participants were followed until completion of a second questionnaire (1994–1998), death, or August 31, 1998. We identified 287 lung cancer cases: 66 incident cases and 221 decedents. Exposure to radiation was inferred based on work history information provided in the baseline questionnaire. Relative risks (RRs) and 95% confidence intervals (CIs) were calculated using Cox proportional hazard models adjusted for age, race/ethnicity and smoking. Smoking-adjusted lung cancer risk was not related to working as a radiologic technologist in early years when radiation exposures were likely highest (RR = 0.9; 95% CI, 0.5–1.8 for year first worked before 1940 compared to year first worked ≥1960), nor was risk related to the year first worked after 1940 or the number of years worked in any decade. While lung cancer risk was increased in radiologic technologists who held patients for X-rays, or who allowed others to take numerous practice X-rays on them, the trend was not statistically significant in either case. Although we adjusted for smoking, the possibility of residual confounding exists. Overall, we find very limited evidence that chronic low-to-moderate dose occupational exposure increased lung cancer risk in the US Radiologic Technologist cohort.
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Moderate to high-dose ionizing radiation has been consistently associated with increased risk of lung cancer.[1] Atomic bomb survivors exposed to a single acute dose of radiation show an increased risk of lung cancer, with relatively little effect modification by age at exposure, time since exposure or attained age.[2,3] Excess risk of lung cancer has also been noted in populations treated with medical radiation for ankylosing spondylitis[4] and peptic ulcers.[5]

It is less clear whether risk of lung cancer is associated with chronic low-to-moderate dose radiation exposures such as those received by radiation workers, patients with repeated diagnostic X-ray procedures, or the general public from environmental exposure. Published reports of lung cancer mortality and incidence among medical workers (radiologists and radiologic technologists) have been inconsistent, with studies reporting increased risk, decreased risk or no association.[6–13] Some of this inconsistency might reflect the inability of most studies to account for cigarette smoking, the strongest environmental risk factor for lung cancer.

We examine the potential relationship between exposure to fractionated low-dose radiation and risk of lung cancer in 71,894 individuals in the US Radiologic Technologist (USRT) cohort. The large size of this cohort compared to other cohorts of medical workers, the availability of detailed smoking information at baseline, and the predominantly female composition (78%) of this cohort allowed us to build on previous studies by adjusting for smoking, and separately assessing risk for men and women.

Material and methods

Study population and case ascertainment

The US Radiologic Technologist (USRT) cohort, a collaborative effort between the US National Cancer Institute, the University of Minnesota, and the American Registry of Radiologic Technologists (ARRT), has been approved annually by the human subjects review boards of the National Cancer Institute and the University of Minnesota.

A detailed description of study methods can be found elsewhere.[14,15] In brief, the study cohort includes 146,022 radiologic technologists residing in the United States and certified by the ARRT for at least 2 years between 1926 and 1982. Annual follow-up is conducted through yearly re-certification with the ARRT. The vital status of cohort members who do not renew certification is determined through various tracing resources, including the Social Security Death Index, National Death Index Plus and address change databases.

Radiologic technologists found to be alive in 1982 (*n* = 132,454) were sent a baseline mail questionnaire during 1983–1989. 90,305 technologists (68%) returned responses with detailed information on work history practices, medical history, smoking behavior, alcohol use and other lifestyle and demographic characteristics. Non-response was greater among technologists certified in earlier decades. A second mailed questionnaire was sent during 1994–1998 to ascertain incident cancers and to update information on work history and other previously collected risk factors. 90,972 of 126,628 radiologic technologists known to be alive at the time of second questionnaire mailing responded (72% overall response rate, 84% of first survey responders).

The lung cancer analysis was restricted to 71,894 baseline questionnaire respondents who were free of cancer other than non-melanoma skin cancer at baseline, and who either responded to the second questionnaire or died before August 31, 1998. Excluded from the analysis were 2,243 respondents with a prior diagnosis of any form of cancer at baseline, 8 deceased subjects for whom questionnaires had been completed by proxy, and 16,160 subjects who did not complete the second questionnaire and were not found to be deceased based on mortality records.

Lung cancer validation

Eligible cases were participants reporting a primary diagnosis of lung cancer (including trachea, bronchus or pleural cancer)

TABLE I – CHARACTERISTICS OF LUNG CANCER CASES AND OTHER RADIOLOGIC TECHNOLOGISTS BY GENDER, US RADIOLOGIC TECHNOLOGISTS HEALTH STUDY, 1984–1998[1,2]

	Male				Female			
	Cases (n = 121)	%	Non-cases (n = 15,829)	%	Cases (n = 166)	%	Non-cases (n = 55,778)	%
Age (in years) completed baseline questionnaire								
<30	0	0.0	1,668	10.5	2	1.2	11,838	21.2
30–39	6	5.0	6,921	43.7	15	9.0	25,858	46.4
40–49	23	19.0	3,790	23.9	38	22.9	11,736	21.0
50–59	42	34.7	2,076	13.1	53	31.9	4,212	7.6
60+	50	41.3	1,374	8.7	58	34.9	2,134	3.8
Year of birth								
<1930	69	57.0	2,187	57.0	78	47.0	3,483	6.2
1930–1939	36	29.8	2,577	29.8	51	30.7	6,858	12.3
1940–1949	15	12.4	5,398	12.4	33	19.9	18,099	32.5
1950–1959	1	0.8	5,633	0.8	4	2.4	26,773	48.0
1960+	0	0.0	34	0.0	0	0.0	565	1.0
Race/ethnicity								
White	105	86.8	14,438	91.2	160	96.4	53,885	96.6
Black	8	6.6	583	3.7	4	2.4	1,115	2.0
American Indian/Alaska native	2	1.7	387	2.4	0	0.0	350	0.6
Asian/Pacific islander	0	0.0	77	0.5	1	0.6	94	0.2
Other or unknown	6	5.0	344	2.2	1	0.6	334	0.6
Education								
High school or less, vocational	17	14.0	766	4.8	8	4.8	1,487	2.7
Radiation technology program	34	28.1	5,009	31.6	91	54.8	33,479	60.0
Some college or graduate school	57	47.1	9,329	58.9	54	32.5	19,097	34.2
Other	1	10.7	597	3.8	11	6.6	1,376	2.5
Unknown	0	0.0	128	0.8	2	1.2	339	0.6
Region of residence								
Northeast	31	25.6	3,328	21.0	43	25.9	14,509	26.0
Midwest	27	22.3	4,298	27.2	42	25.3	18,133	32.5
South	38	31.4	4,447	28.1	52	31.3	13,591	24.4
West	25	20.7	3,754	23.7	29	17.5	9,536	17.1
Unknown	0	0.0	2	0.0	0	0.0	9	0.0
Marital status								
Currently married	99	81.8	12,740	80.5	95	57.2	41,800	74.9
Divorced or separated	14	11.6	1,232	7.8	21	12.7	5,657	10.1
Widowed	2	1.7	131	0.8	27	16.3	1,070	1.9
Never married	5	4.1	1,499	9.5	21	12.7	6,719	12.1
Unknown	1	0.8	227	1.4	2	1.2	532	1.0
Smoking status at baseline								
Never	5	4.1	6,001	37.9	14	8.4	28,412	50.9
Ever	116	95.9	9,797	61.9	152	91.6	27,293	48.9
Ex-smoker	45	37.2	5,683	35.9	35	21.1	14,140	25.4
Current smoker	67	55.4	3,942	24.9	111	66.9	12,748	22.9
Unknown	4	3.3	203	1.3	6	3.6	478	0.9
Pack-years smoked								
0	5	4.1	6,047	38.2	14	8.4	28,594	51.3
1–9	8	6.6	3,452	21.8	5	3.0	14,196	25.5
10–19	11	0.1	2,224	14.1	19	11.5	6,066	10.9
20–29	14	11.6	1,348	8.5	30	18.1	2,941	5.3
30–39	24	19.8	975	6.2	22	13.3	1,660	3.0
40+	51	42.2	1,314	8.3	62	37.4	1,429	2.6
Smoked, unknown amount	0	0.0	438	2.8	14	8.4	819	1.5
Unknown	8	6.6	31	0.2	0	0.0	73	0.1

[1]Restricted to baseline questionnaire respondents who were free from cancer other than non-melanoma skin at time of response (1983–1989).–[2]Characteristics reflect status as of response to the baseline questionnaire.

occurring between the two questionnaires, as well as participants who completed the first questionnaire but died before August 31, 1998, with lung cancer listed as the underlying cause of death (ICD8 = 162), as determined by linkage with the National Death Index.

Medical records were obtained for 68% of subjects who reported lung cancer between the first and second surveys, and primary lung cancer diagnoses were found to be correct for 87% of these. All of the incorrect reports were found to be metastases to the lung from another anatomic site.[15] Given the high proportion of self-reported lung cancers that were validated by medical records, we included in the analysis incident cases for whom medical record confirmation could not be obtained. Overall, we identified 66 incident first primary lung cancers and 221 lung cancer deaths.

Job history and work practices

Since individual radiation dose estimates were not available, we evaluated lung cancer risk according to respondents' answers to lifetime job history and work practice questions on the baseline questionnaire. Medical radiation workers employed in calendar periods before 1950 are reported to have higher radiation exposures[16,17] than those working in later time periods because of changes in technology and permissible exposure limits.[18] Accordingly, exposures were estimated based on year first employed and years employed before 1950, 1950–59 and 1960 onwards. We also assessed whether lung cancer risk in radiologic technologists was associated with age first worked or with indicators of high personal exposure, such as holding patients for X-ray procedures, or allowing other technologists to take practice X-rays on oneself.

TABLE II – AGE-ADJUSTED RELATIVE RISKS (RRs) AND 95% CONFIDENCE INTERVALS (CI) FOR LUNG CANCER ASSOCIATED WITH SMOKING PRACTICES AMONG MALE AND FEMALE RADIOLOGIC TECHNOLOGISTS, US RADIOLOGIC TECHNOLOGIST HEALTH STUDY[1]

Characteristic	Male		Female		Overall	
	No. of cases ($n = 121$)	RR	No. of cases ($n = 166$)	RR	No. of cases ($n = 287$)	RR
Smoking status						
Never smoked	5	1.0	14	1.0	19	1.0
Former smoker	45	5.5 (2.2, 13.9)[2]	35	3.9 (2.1, 7.3)	80	4.8 (2.9, 8.0)
Current smoker	67	20.0 (8.0, 49.7)	111	17.4 (9.9, 30.6)	178	18.1 (11.3, 29.2)
Cigarettes smoked per day						
0	5	1.0	14	1.0	19	1.0
1–9	9	3.9 (1.3, 11.8)	10	2.0 (0.9, 4.5)	19	2.6 (1.4, 4.9)
10–19	36	7.9 (3.1, 20.1)	62	10.0 (5.6, 18.0)	98	9.2 (5.6, 15.1)
20+	70	15.1 (6.1, 37.5)	77	18.7 (10.5, 33.3)	147	17.5 (10.8, 28.3)
Years smoked at baseline						
0	5	1.0	14	1.0	19	1.0
1–9	0	–	6	2.2 (0.8, 5.8)	6	1.5 (0.6, 3.9)
10–19	10	4.2 (1.4, 12.3)	9	2.4 (1.0, 5.7)	19	3.2 (1.7, 6.1)
20–29	18	6.1 (2.3, 16.6)	32	7.0 (3.7, 13.4)	50	6.9 (4.0, 11.8)
30+	81	19.3 (7.6, 48.7)	94	20.6 (11.3, 37.5)	175	21.0 (12.7, 34.5)
Pack-years smoked						
0	5	1.0	14	1.0	19	1.0
1–9	8	3.1 (1.0, 9.4)	5	0.9 (0.3, 2.5)	13	1.6 (0.8, 3.2)
10–19	11	5.8 (2.0, 16.7)	19	6.6 (3.3, 13.2)	30	6.4 (3.6, 11.5)
20–29	14	7.7 (2.8, 21.6)	30	12.7 (6.7, 24.3)	44	10.7 (6.2, 18.5)
30–39	24	15.0 (5.7, 39.5)	22	12.5 (6.3, 24.5)	46	14.3 (8.4, 24.6)
40+	51	17.0 (6.7, 42.8)	62	25.6 (14.1, 46.6)	113	22.2 (13.5, 36.3)

[1]Smoking characteristics calculated from baseline questionnaire responses (1983–1999).–[2]Values in parentheses indicate 95% CIs.

Smoking history

For respondents who reported smoking more than 100 cigarettes in their lifetime, information on age of starting and stopping smoking cigarettes and smoking intensity (<½ pack per day, ½ to 1 pack per day, 1–2 packs per day, ≥2 packs per day) was obtained from the baseline questionnaire. Number of years and pack-years smoked were derived from the answers to these questions.

Statistical analysis

Participants were followed from the return date of the baseline questionnaire until death, the return date of the second study questionnaire, or August 31, 1998, whichever occurred first. Cox proportional hazards modeling was used to compute hazard ratios (HRs) with 95% confidence intervals (CIs). Age was used as the time scale, beginning with age at completion of the first questionnaire.[19] The response variable was age at lung cancer diagnosis or death, and subjects were censored at the date of return of the second questionnaire, or date of first cancer other than non-melanoma skin cancer (to minimize possible bias introduced by differential behaviour of cancer patients). To control for secular trends, models were stratified by birth cohort in 5-year intervals. Missing information was coded to indicator variables, in order to retain observations in the regression models.

All models were adjusted for race/ethnicity and smoking (incorporating never/former/current status as well as pack-years categorized as none, 1–19, 20–39 or 40+). Risk ratios were assessed overall, and for males and females separately. Estimates of lung cancer risk associated with the decade of first working as a radiologic technologist were adjusted for the total number of years worked. Models estimating lung cancer risk for duration of employment during specific time periods were restricted to subjects eligible to work in that time period and adjusted for duration of work during other time periods. Tests for trend were conducted for non-missing values using the underlying continuous variable where possible, or using category midpoints when data were collected as categories; p-values are 2-sided.

Results

Descriptive characteristics

Descriptive characteristics of the study population are summarized in Table I. Lung cancer cases were slightly less well educated than non-cases. Race/ethnicity and marital status distributions were largely similar, with the exception that female lung cancer cases were more likely to be widowed than female non-cases. Approximately half of the study population (52%) were smokers, with this proportion being higher in men than in women and as expected, much higher in cases than in non-cases (93% of cases *versus* 53% of non-cases indicated ever smoking). Lung cancer cases were also heavier smokers than non-cases. Ever smoking cigarettes was strongly and consistently associated with lung cancer risk in both men (RR = 9.8, 95% CI = 4.0–23.9) and women (RR = 9.4, 95% CI = 5.4–16.3). Compared to individuals who had never smoked, the relative risks (RRs) of lung cancer (95% CI) for individuals who had smoked for 1–9 years, 10–19 years, 20–29 years, 30–39 years and 40 or more years were 1.6 (0.8, 3.2), 6.4 (3.6, 11.5), 10.7 (6.2, 18.5), 14.3 (8.4, 24.6) and 22.2 (13.5, 36.3), respectively. RR estimates for lung cancer for smoking 1–9 cigarettes, 10–19 cigarettes and more than 20 cigarettes per day (compared to non-smokers) were 2.6 (1.4, 4.9); 9.2 (5.6, 15.1) and 17.5 (10.8, 28.3), respectively (Table II).

Risk associated with job history, work practices and procedures

Decade of first working, calendar year first worked and number of years worked before 1950 were not associated with risk of lung cancer (Table III). Although earlier age of first working as a radiologic technologist was associated with increased risk of lung cancer for men (RR = 2.1; 1.0–4.2 for <20 years compared to 30+), the test for trend was not significant, and this pattern was not seen for women. Lung cancer cases reported holding patients for X-rays more frequently (≥50 times *versus* 10 or less; RR = 1.5; 1.0–2.2) and having more practice X-rays taken on them (≥25 *versus* none; RR = 1.8; 1.1–2.9) than non-cases. As shown in Table III, adjusting for smoking reduces the RRs, but does not substantially alter the results.

Discussion

Our data overall provided very limited evidence that low-to-moderate dose occupational exposure was associated with lung cancer risk in the USRT cohort. Lung cancer risk was not associated with the surrogate measures of year began working as a radiologic technologist or the number of years worked in early calendar periods. Previous analyses of the USRT cohort have shown that

TABLE III – RACE/ETHNICITY-ADJUSTED RELATIVE RISKS (RRs) AND 95% CONFIDENCE INTERVALS (CIs) FOR LUNG CANCER AMONG MALE AND FEMALE RADIOLOGIC TECHNOLOGISTS ASSOCIATED WITH YEARS WORK AS A RADIOLOGIC TECHNOLOGIST AND SELECTED WORK PRACTICES, US RADIOLOGIC TECHNOLOGIST HEALTH STUDY[1][2]

Characteristic	Male			Female			Overall		
	No. of cases (n = 121)	Unadjusted for smoking RR	Adjusted for smoking RR	No. of cases (n = 166)	Unadjusted for smoking RR	Adjusted for smoking RR	No. of cases (n = 187)	Unadjusted for smoking RR	Adjusted for smoking RR
Calendar year first worked as a radiologic technologist[3]									
1960+	28	1.0	1.0	44	1.0	1.0	72	1.0	1.0
1950–1959	40	1.3 (0.7–2.5)[4]	1.3 (0.7–2.4)	61	1.0 (0.6–1.8)	0.9 (0.5–1.6)	101	1.0 (0.7–1.5)	1.0 (0.7–1.5)
1940–1949	41	1.7 (0.8–3.7)	1.4 (0.7–3.1)	35	0.8 (0.4–1.5)	0.7 (0.4–1.4)	76	1.0 (0.6–1.6)	1.0 (0.6–1.5)
<1940	8	1.6 (0.5–4.7)	1.2 (0.4–3.6)	19	1.0 (0.4–2.2)	1.0 (0.4–2.2)	27	1.0 (0.5–1.9)	0.9 (0.5–1.8)
Number of years worked before 1950[5]									
0	37	1.0	1.0	52	1.0	1.0	89	1.0	1.0
1–4	27	1.3 (0.7–2.3)	1.1 (0.6–2.0)	23	0.7 (0.4–1.2)	0.7 (0.4–1.2)	50	0.9 (0.6–1.4)	0.9 (0.6–1.3)
5–9	14	0.9 (0.4–2.0)	0.8 (0.4–1.8)	21	1.0 (0.5–1.9)	1.1 (0.6–2.0)	35	1.0 (0.6–1.6)	1.0 (0.6–1.6)
10+	8	1.4 (0.5–3.7)	1.1 (0.4–3.0)	10	0.7 (0.3–1.6)	0.7 (0.3–1.7)	18	0.9 (0.5–1.7)	0.9 (0.5–1.6)
Number of years worked 1950–1959[5]									
0	25	1.0	1.0	42	1.0	1.0	67	1.0	1.0
1–4	25	1.4 (0.8–2.7)	1.3 (0.7–2.5)	51	1.1 (0.7–1.8)	1.0 (0.6–1.6)	76	1.1 (0.8–1.6)	1.1 (0.8–1.6)
5–9	61	1.5 (0.8–2.8)	1.3 (0.7–2.6)	54	1.0 (0.6–1.6)	0.8 (0.5–1.4)	115	1.1 (0.8–1.7)	1.0 (0.7–1.5)
Number of years worked 1960 or after[5]									
0	13	1.0	1.0	28	1.0	1.0	41	1.0	1.0
1–4	9	0.8 (0.3–2.0)	1.0 (0.4–2.4)	21	1.1 (0.6–2.1)	1.1 (0.6–2.0)	30	1.0 (0.6–1.7)	1.0 (0.6–1.7)
5–9	95	0.8 (0.4–1.5)	0.8 (0.4–1.6)	110	1.1 (0.7–1.8)	1.0 (0.6–1.7)	205	1.1 (0.7–1.6)	1.0 (0.7–1.5)
Age first worked (in years)[3]									
30+	17	1.0	1.0	35	1.0	1.0	52	1.0	1.0
25–29	33	1.9 (1.0–3.5)	1.9 (1.0–3.6)	14	0.6 (0.3–1.2)	0.7 (0.4–1.4)	47	1.1 (0.8–1.7)	1.2 (0.8–1.8)
20–24	43	1.6 (0.9–2.9)	1.5 (0.8–2.7)	59	0.9 (0.6–1.4)	1.0 (0.6–1.6)	102	1.1 (0.7–1.5)	1.1 (0.7–1.6)
<20	24	2.6 (1.3–5.2)	2.1 (1.0–4.2)	51	0.8 (0.5–1.3)	0.8 (0.5–1.4)	75	1.1 (0.7–1.6)	1.1 (0.7–1.6)
Number of times held patients for X-rays									
<10	8	1.0	1.0	22	1.0	1.0	30	1.0	1.0
10–24	15	2.4 (1.0–5.8)	2.4 (1.0–5.7)	23	1.3 (0.7–2.4)	1.3 (0.7–2.4)	38	1.7 (1.0–2.7)	1.7 (1.0–2.7)
25–49	12	2.2 (0.9–5.4)	1.9 (0.8–4.7)	27	1.5 (0.8–2.6)	1.3 (0.7–2.2)	39	1.7 (1.0–2.7)	1.5 (0.9–2.4)
50+	81	2.7 (1.3–5.7)	2.1 (1.0–4.3)	84	1.5 (0.9–2.4)	1.2 (0.7–1.9)	165	1.9 (1.3–2.8)	1.5 (1.0–2.2)
p-trend		<0.01	0.2		0.1	0.7		0.0	0.2
Number of times allowed others to take practice X-rays									
0	79	1.0	1.0	126	1.0	1.0	205	1.0	1.0
1–9	20	1.3 (0.8–2.2)	1.6 (1.0–2.6)	23	1.2 (0.8–1.9)	1.1 (0.7–1.7)	43	1.3 (0.9–1.8)	1.3 (0.9–1.8)
10–24	5	0.5 (0.2–1.3)	0.5 (0.2–1.3)	5	0.7 (0.3–1.6)	0.7 (0.3–1.6)	10	0.6 (0.3–1.2)	0.6 (0.3–1.1)
25+	12	1.9 (1.0–3.5)	1.8 (0.9–3.3)	6	2.5 (1.1–5.8)	1.9 (0.8–4.5)	18	2.2 (1.4–3.7)	1.8 (1.1–2.9)
p-trend		0.3	0.4		0.3	0.5		0.1	0.2

[1]Restricted to responders to the baseline questionnaire (1983–1989) who were free of cancer other than non-melanoma. Risk estimates shown with and without adjustment for smoking skin cancer at the time of response. Incident lung cancers are the first cancer other than non-melanoma skin cancer reported either on the follow-up questionnaire (1994–1998) or as the underlying cause of death on death certificates or NDI-*Plus*; comparison subjects either responded to a follow-up questionnaire or died by August 1998.–[2]Relative risks were estimated using Cox proportional hazards regression analysis; all analyses were adjusted for age (time-scale), stratified on birth cohort in 5-year intervals, and additionally adjusted for race/ethnicity. Smoking-adjusted models were adjusted for never/former/current smoking and pack-years smoked. Study exit is defined as date of diagnosis for lung cancer cases and the earliest of date of first cancer other than non-melanoma skin cancer, questionnaire response or death for non-cases.–[3]Adjusted for total years worked.–[4]Values in parentheses indicate 95% CIs.–[5]Restricted to subjects eligible to work in this time period, and additionally adjusted for years worked in other time periods.

working in early calendar years was associated with increased risk of breast cancer,[20] leukemia other than chronic lymphocytic leukemia,[21] basal cell carcinoma[22] and melanoma.[23] In analyses adjusted for cigarette smoking, we found that lung cancer risks were higher in radiologic technologists who frequently held patients for X-rays, and in those who allowed others to take numerous practice X-rays on them. However, the trend was not significant for either of these variables. While our observed risks for smoking and lung cancer are consistent with other studies, it is possible that our work-related findings could have been impacted by residual confounding.

Based on data from the atomic bomb survivors, as well as studies of patients treated with medical X-rays, ionizing radiation has been established as a risk factor for lung cancer. The Life Span Study, which consists of about 120,000 survivors of the atomic bombings in Japan, reported an excess RR of 0.95 (95% CI, 0.60–1.4) per Sievert for lung cancer.[3] In a joint analysis of smoking and radiation, Pierce et al. found the effects of smoking and radiation on lung cancer were consistent with an additive model of interaction.[24] Although early analyses of atomic bomb survivors indicated a stronger relationship between radiation and lung cancer for women than for men, adjustment for smoking in later analyses accounted for most of the gender difference. Studies of irradiated medical populations have also shown increased risk of lung cancer: patients treated with radiation for ankylosing spondylitis had a significant excess of lung cancer (ERR per Gy = 0.09, 95% CI, 0.03–0.15) in the period 5–24 years after treatment, with an average dose to the bronchi of 8.88 Gy.[4] Peptic ulcer patients who received doses of <1.4 Gy (mean dose 1.1 Gy) were found to have an ERR of 0.43 per Gy (95% CI, 0.12–1.35).[5] On the other hand, data from a large cohort study of tuberculosis patients exposed to repeated fluoroscopic examinations did not show evidence of an association between risk of lung cancer and dose (mean total dose to the lung was 1.02 Gy).[25]

Our finding of limited evidence of lung cancer risk with work as a radiologic technologist is generally consistent with previous studies of medical radiation workers. No excess lung cancer risk was observed in US army radiologic technologists followed from 1946–1974,[8] in Danish radiotherapy workers employed during 1954–1982,[6] or in Japanese radiologic technologists born in 1950 or earlier.[13] An excess of lung cancer mortality was reported in British radiologists who were registered before 1920,[12] while no excess was seen in individuals who registered in later years when doses would have been much lower.[11] Increased lung cancer incidence in a cohort of Chinese X-ray workers was only seen in individuals who started work after 1970, but not in individuals who started work in earlier years,[9] suggesting that this association could have been due to confounding by smoking, which would have been more prevalent in later years. While this is the first study of risk of total lung cancer risk (incidence and mortality) in the USRT cohort, previous analyses indicated that observed incident lung cancers and lung cancer deaths in the USRT cohort were lower than in the general US population, possibly because of lower prevalence of smoking in the USRT cohort than in the general population.[10,15]

The USRT cohort is one of the largest prospective cohort studies of chronic low-to-moderate radiation exposure. The strengths of this analysis compared to previous lung cancer studies in medical radiation workers include the collection of incident cancers as well as cancer deaths, the ability to control for individual smoking history, and inclusion of a large number of women in the study population. While the main limitation of this study is the lack of individual dosimetry data, elevated risks have been found for breast, basal cell carcinoma, melanoma and leukemia (other than CLL) using the proxy measure of year first worked as a radiologic technologist. It is possible that this measure was not sufficiently sensitive to detect a weaker association with lung cancer, especially given the presence of smoking, a very strong risk factor for lung cancer, in most of our cases. The fact that smokers were less likely to have responded to the second survey than do non-smokers may limit the generalizability of our results. However, smoking was only moderately correlated with variables describing radiation exposure, and standardized incidence ratios calculated for lung cancer did not change appreciably when the authors weighted for non-response in that analysis.[15] Although not all lung cancers were validated, the confirmation rate for lung cancer death as a designated cause of death on US death certificates is very high (94%),[26] and we found a high rate of validation for self-reported lung cancers in our study. Finally, it is possible that we underestimated the effect of radiation if most radiation-related lung cancer cases occurred in our cohort before administration of the baseline questionnaire in 1983.

In summary, we find very limited evidence that working as a radiologic technologist increased lung cancer risk in the USRT cohort. Given that lung cancer has been associated with radiation in several studies, including the Life Span Study of atomic bomb survivors, it is important to revisit the issue of lung cancer risk from chronic low-to-moderate radiation doses in a study with more detailed individual dose estimates.

Acknowledgements

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